STEM EDUCATION THROUGH WATER QUALITY SENSING

MAE 4221/5220 Internet of Things
Professor Zhang
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Executive Summary

The Internet of Things (IoT) course at Cornell University was developed to teach Cornell students how to collect data and connect devices using The Things Network (TTN). More importantly, students in this course are taught to apply this knowledge to the real world, engaging with the community to create IoT devices geared toward the betterment of society. As the STEM Education team, our motivation for this project was to contribute to the greater community through educating students. We wanted to use our knowledge of IoT and our experience as relatively recent high school students to develop an engaging new curriculum for students at Geneva High School (GHS).

Our vision for this project was for students to gain experience using the Internet of Things and to spark their interest in engineering. Our design objective was to establish a four-part lesson plan organized so that students would start with knowledge they already had and gradually incorporate more complex components. We worked with our community partner to ensure the project was relevant to their coursework so that the students would be applying a new concept to a topic they already understood. Within this lesson plan, our goals were to give an overview of IoT and how it is used in the real world; teach students how to wire a basic circuit; and involve students in the process of building a sensor package that would send live data to Things Network.

The community partner we worked with was Kirsten Abbott, a Chemistry Science teacher at Geneva High School. Kirsten gave her students the initial introduction to IoT, worked with us ("The Cornell IoT team") to develop the IoT curriculum, and integrated this curriculum into her class. She facilitated communication between us and the high schoolers, hosted our Zoom and in-person lessons, and taught us how to best engage the students. Having an engaged community member was critical to the success of this project.

The IoT system we designed for this project was a sensor package to collect data on the quality of water. This package consisted of a turbidity, temperature, and total dissolved solids sensor. We showed the students how each individual sensor was connected on a breadboard. The Cornell IoT team compiled the sensors into one package. Then, the students helped install the package in the pond at Geneva High School and saw preliminary live data as it came in on The Things Network. We were limited by battery capacity and gateway accessibility. In the future, we hope groups can conserve the device's power and permanently install a gateway at Geneva High School.

Through this project we hoped to address two challenges: making enhanced quality STEM education accessible to all students through a class curriculum, and exposing students to engineering as a potential career path. Based on our student exit survey, we believe we made progress in both these areas, and hope that future STEM teams can build off this work and establish a long-term IoT curriculum in schools outside of Cornell.

Social Context

Many high schools in rural parts of the United States do not have an intensive STEM program that is updated enough to incorporate the shift in technology in the real world. This deprives many students of valuable skill development and real world exposure. After enrolling in this Internet of Things (IoT) class at Cornell and learning about the endless opportunities that are paved by having knowledge on IoT, we felt compelled to share this knowledge with high school students. These students are already using IoT through devices that they own such as smart watches, digital maps on their phones and home security systems, but they might not have been aware of it. As older students, we wanted to bring awareness to them. This is really important because these young people hold the key to our future, so it is our responsibility and our duty to equip them with the knowledge and skills that they actually need to thrive in an ever-evolving landscape. We wanted the students to have an idea on how IoT has been transforming the world by revolutionizing industries and shaping economies. We hope that we were able to ignite their curiosity, inspiring them to be more innovative as we championed progress and nurtured seeds of possibility. We also wanted this to become a well structured part of the high school curriculum, allowing us to not only benefit the current group of students but also the future generations.

By incorporating a hands-on activity focused on water quality detection, we aimed to reinforce the IoT knowledge we're imparting to the students. This practical experience allowed them to directly engage with collected data, empowering them to make informed decisions regarding water quality assessment. We chose water quality detection because it is already a part of the curriculum and extending the topic with a practical aspect would not be a challenge. Also, we realized it would be easy to integrate something that our students use daily and see how IoT can help them gather some useful information. According to a journal article *Place Matters: Preparing STEM Teachers for Rural Schools*, incorporating local resources for STEM teaching and learning is very effective, as the author writes “When local water quality or weather patterns or changing community demographics become sites for learning STEM concepts, students learn the curriculum, and they also learn that their experiences are valuable and the places they are from are worthy of study (Dubel & Sobel, 2010)” [1]. Our project gave them an immediate opportunity to apply the knowledge they had learned by testing the quality of the water they use for everyday activities like drinking, cooking, or swimming.

Since we were carrying on with the project initiated by the previous group in this class, we seamlessly transitioned into the existing community partnerships required for our project and these partners included Kirsten Abbott and Dr. Kenneth Schlather. Kirsten Abbott teaches Chemistry at Geneva High School, and we collaborated with her to ensure effective student education. She provided valuable insights into the students' current knowledge of water quality, circuitry, and programming, which helped in our planning process. Dr. Kenneth Schlather is the community partner coordinator of the NSF project on public IoT networks that we used. He was expected to provide us with additional guidance as we started sending the collected data to The Things Network and retrieving it through our devices. However, we later realized that there was no need to involve him since the data we collected was only for classroom use and was not going to be shared to any public repository. Jackie Augustine is an environmentalist who has worked with the students before and we thought she would help us with tips on how to best interact and engage with students when teaching them material that is outside of their standard curriculum, but we also ended up not working with her due to time conflicts with other groups that were working with her. In the end, we coordinated with Kirsten only for this education project and the results were favorable.

In terms of broader impact, we anticipate that exposure to IoT will significantly aid students in career exploration. Given the innovative nature of this technology, we believe it provides them with a broader perspective on the numerous ways they can shape their career paths. This is especially crucial considering recent findings reported by the U.S. News Article, where a notable portion of high school students expressed the need for more opportunities in career exploration. As highlighted in the article, "Research shows that two out of three high school students and recent high school graduates say they would have benefited from more career exploration in middle and/or high school"[2].

High school students are the future leaders of tomorrow and it's essential for them to understand the critical role of IoT, particularly in fields like healthcare and water quality management. According to the World Health Organization (WHO), a staggering 80% of the world's diseases, 50% of child deaths, and over 50 diseases are attributed to poor water quality. By empowering high schoolers with the ability to collect and analyze water quality data through IoT, we are enabling them to make a tangible impact on global health outcomes. Not only can they gain a deeper understanding of the issues at hand, but they will also have the opportunity to educate their own households, thereby amplifying awareness and effecting significant change in their communities and beyond.

Review of Related Work

Our key takeaways from the previous two years' iterations of the STEM Outreach project is that a majority of students are unfamiliar with IoT technology, in its use and even its existence. According to a survey taken by the 2023 team of the participating Geneva Green Club students, students on average came in with little familiarity and no technical exposure to IoT, and left with a greater interest in learning more in the field.

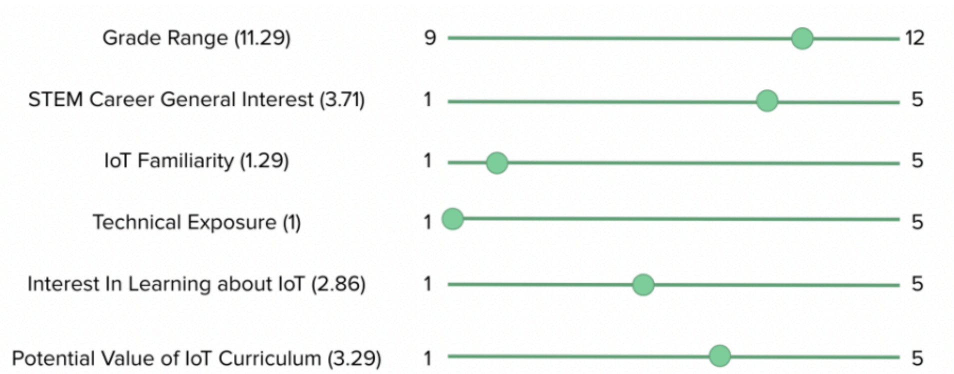

Figure 1: Green Club Survey Results 2023. The grade range indicates what year the students were in (9th through 12th grade). The rest of the survey questions were answered on a scale of 1 to 5, with 1 being the least of the given quality and 5 being the most.

Through analysis of previous curriculums and design approaches, our team determined that students may feel a disconnect from the content they are being shown. At the end of the 2023 IoT team's student engagement, the high school students completed a feedback survey. The results of the survey reflect a high interest in STEM careers among participants, but the sample is not representative of all high school students (Figure 1). The survey was given to members of the Green Club, a club which students may voluntarily join, likely because their interests align with those which the club promotes. According to Kirsten, students in her classes have no coding experience and a very brief exposure to electrical systems through a project which she gave them herself. With this knowledge, we aimed to develop an IoT curriculum which is not completely independent as its own course or small workshop, but instead integrated within the curriculum which students are already required to follow.

The future plans of the 2023 team involved expanding their pilot lesson into an after-school club at the high school focused on IoT systems. The group mentions that a club, while still having its own restrictions of budget, timing, space, and staffing, is more realistic to implement at Geneva high school than an entirely new IoT focused course. A club, however, has the aforementioned limitations, as well as those biases which came with the survey results. A club would provide students a way to explore their existing interests, but not necessarily work to expose uninterested or unfamiliar students to IoT.

Implementing this after school program was the team's short-term goal. Their long term goal was to implement a sustainable IoT curriculum across schools in and out of state. With our new perspective, we are slightly modifying the previous goals by integrating IoT into classrooms like Kirsten's chemistry class. We aim to show students that IoT is not so much an isolated field, but rather a medium to explore science and engineering. We believe this will be more sustainable than an independent curriculum because it can build off of a foundation which already exists and is widely normalized within high schools. Teaching IoT during the school day also ensures accessibility for students who are unable to stay after school to participate in extracurricular activities.

In addition to integrating IoT into subjects that are relevant to the students, we want to extend the impact of this education on students by allowing them to receive and analyze data over a long period of time. Unlike a workshop on temperature sensors measuring the room temperature, our idea of water quality detection will allow students to track data relevant to their studies over a few days

Project Scope

Vision and Design Objective

Our vision was for students to see the value of collecting data using a LoRaWAN network through completing an IoT project. We worked with our community partner to ensure this project was relevant to their coursework so that the students would be applying a new concept to a topic they already understood. We wanted students to learn about the usefulness of the Internet of Things and spark their interest in engineering. Our design objectives were in line with this vision: create a four-part lesson plan introducing students to IoT and giving them hands-on experience with engineering design and mechatronics. The steps taken to achieve our visions and objectives were feasible for one semester, and are listed as follows:

1) Introduce ourselves and the project to students on Zoom. Give them an initial design project–creating a waterproof case for the sensors–to introduce them to engineering design (Appendix 10).
2) Go to Geneva High School in person to show the students how to connect each sensor (turbidity, temperature, and total dissolved solids). Split students into groups to work on each sensor on a different breadboard. Each group had one Cornell IoT team member.
3) On Zoom, explain to students how these sensors send data to The Things Network. Show the students where live data appears on The Things Network website and briefly go through the code we wrote.
4) Go to Geneva High School to install the final sensor package in the pond (seen in Appendix 9) and watch live data come in. Later, send the data to the students in PDF form as well as a worksheet explaining how to interpret the numbers.

Design Process and Community Partner Involvement

We worked closely with our community partner, Kirsten Abbott, to devise a plan on how to best conduct our education project. The first task was to inquire about the depth of the students' background knowledge of Mechatronics. We learned that they only knew the basics and they had done only one hands-on project where they had to connect an LED to a Greeting card and they struggled with it. With that in mind, we drafted a concrete teaching plan that would educate the students from the basics of circuits to the practical implementation of electronics that forms the basis of the Internet of Things. Our main constraint was the geographical separation between

Geneva High School and Cornell University. With Geneva High School being approximately an hour drive away, we had to be methodical in our education approach to ensure efficiency. Given the time limitation—the 50 minute period allocated for our IoT lecture—and the impracticality of commuting between the two locations without missing subsequent classes, we opted for a hybrid educational model. The virtual lessons were dedicated to theoretical aspects of the education, whilst the in-person lessons would be for the hands-on activities.

To facilitate this, we structured the educational journey into four distinct phases, each tailored to achieve specific learning objectives and accommodate the hybrid learning objectives. The first phase—which was spread over two class meetings—was the introduction of the project scope to the students and this was facilitated by both Kirsten and our team. Kirsten conducted the introductory lesson on what IoT is, shedding light on how the students would be working with the Cornell team and noted down their choice of the sensor they would like to work on, as well as all the questions that the students had. The next lesson was led by our team, and we got to interact with the students virtually, answering all the questions they had submitted to Kirsten during the first lesson. During this lesson, we gave the class a chance to know us better on a more personal level by sharing our goals and aspirations with them. During the second learning phase (which was completed in one period), we visited Geneva High School and did our first hands-on lesson in person. This lesson was led by our team, with Kirsten helping us to group the students into smaller teams based on their preference for the type of sensor they wanted to explore. The main objectives of this lesson included giving the students the fundamentals on how to build complete circuits, connect sensors to 'read' input values and visualize output data through the Serial Monitor of the Arduino Software. The students also learned how to interpret the output sensor values in relation to water quality detection.

The last two learning phases were focused on sending data to the Internet and retrieving it for analysis. The third learning phase was a brief recap of the basics of Mechatronics, followed by a demonstration on how data collected from the sensors is sent to the Internet via The Things Network platform. Since this was mostly theoretical, this lesson was virtual. The students were able to watch as the live data got streamed on the output console and understand how the transmitted data could be decoded for comprehension. The final learning phase, which was done in person, was the most engaging lesson. Alongside Kirtsen, the Cornell IoT team led the students in deploying the sensor packages into the pond. Together, we witnessed the first batch of data come in through TTN and saved it on a computer drive using a Python script (Appendix 2).

Community Response

As mentioned previously, we had 4 sessions with the students and we made adjustments to the subsequent lessons based on student engagement, response, and feedback from the lesson before that. After the first lesson (over Zoom), it was clear that the students had no experience with mechatronic systems, and had only a slight interest in learning more about IoT. To acquire feedback after each lesson, the students had to submit an "exit ticket", which was a summary of what they learned and one question they had, and responses were minimal. Examples of the questions submitted were "How can we tell what's in the water if we can't see it?", "What could be the greatest extent to sensor technology?", and "Can we put a camera in the sensor package?" and we made sure to answer these questions in the following lessons. For the second learning phase that was done in person, we received very positive feedback from our community partner as well as the school. Our visit was on a Friday, and by the following Monday, the school had already updated its website to feature a picture of the students working on the mechatronics activity that we led them to (Figure 2).

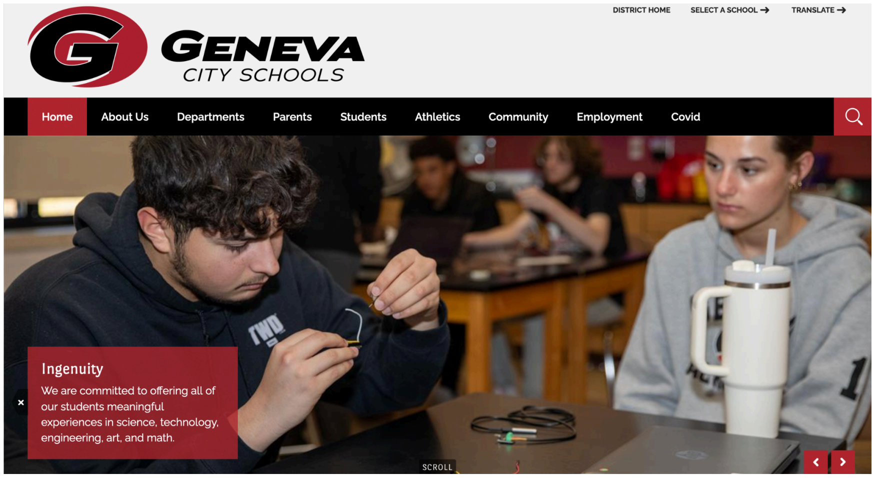

Figure 2 (left): In-Person Lesson with Students - Image Featured on Geneva District Website

Figure 3 (right): In-Person Lesson with Students - Image on Geneva City School District Official Instagram. Caption reads, "Cornell University students have been working with a science class at GHS to build sensors for testing water temperature, turbidity, and particulates. The work has included Zoom and in-person lessons with the Cornell students, with plans for deploying the sensors in the pond behind the school as the final piece."

A few days after our visit, the photos were also uploaded on their official Instagram page (Figure 3). One of the best forms of community response is seeing how enthusiastic the school is about promoting STEM education in the district. To have our lesson featured on the main web page and Instagram shows how valuable our work with these students is, and how much a fully implemented STEM curriculum would impact the school.

In our last learning phase we implemented the device in the pond on the high school property (see figures in Appendix 8). Despite the rainy weather, all present students willingly went outside to install the sensors with us, and most of them seemed excited. Throughout the whole process the students were engaged with the different steps taken for the installation procedure. For instance, some students assisted us with connecting the battery and some others helped secure the device to the stick supporting the device, ensuring it would not be submerged in the water. Everyone was eager to be involved somehow in the implementation process.

Kirsten remarked, "The IoT team collaborated and created equitable STEAM lessons that modeled academic excellence. In a short time, the team built relationships with students. All of the students went outside in the rain to install the sensors into the pond, a testament to the IoT Team's ability to connect with students and also in connecting students with relevant content."

After the four learning phases, we sent out a survey to the students to collect feedback on how these lessons were impactful to them (Figure 4). From the responses, we can see that most of the students were not familiar with circuits, sensors and IoT. Even though the responses showed mixed feelings on what the students think of STEM, we can tell that they all appreciate the opportunity of getting IoT education based on their responses to the question “Would it be valuable to have lessons like this within your class more often”, which had an average rating score of 3.78 out of 5.

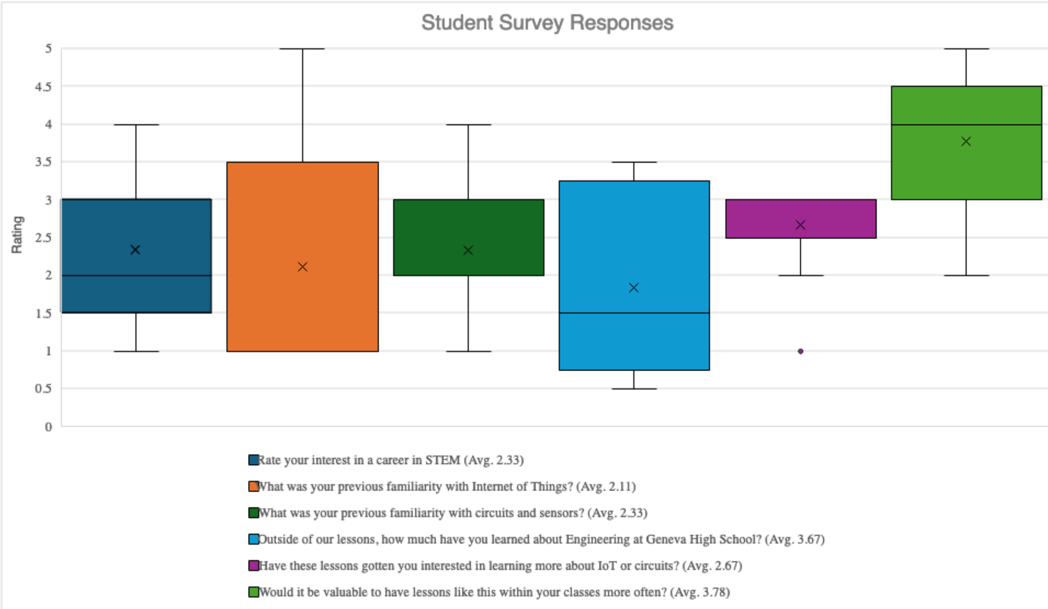

Figure 4: A chart showing the responses to the survey questions sent to the students. 9 of them responded and the highest average rating score (3.78 out of 5) was in favor of having lessons on IoT in their classes more often.

IoT System Under Consideration

The students observed water quality through building IoT systems that measured total dissolved solids (TDS), temperature, and turbidity. TDS varies between different bodies of water, but significant increases over time can indicate pollution. A TDS value above 1000 mg/L could indicate an existing quality issue. The temperature of water varies with weather conditions, but unusual changes could be due to pollution. Turbidity measures particulate matter in water. In a pond this could be sediment, organic matter, or pollutant. Data was collected using sensors that measured these conditions of water, and plot of this data over time is shown in the data analysis worksheet (Appendix 7). We used a featherboard with LoRaWAN capabilities and an external Lithium Ion Polymer battery so the sensors can run while separated from a computer (the complete list of materials for these sensors is shown in the Bill of Materials in Appendix 1). The non-waterproof electronics were enclosed in a waterproof case of the students’ choosing.

The data collection in this project had no privacy concerns for the students. Only temperature, turbidity, and particulate data was shared across the network. We had no legal or security concerns. Of course, animals or nature could have interfered with our system, but we did our best to design and implement our hardware so that both our sensors and wildlife remained unbothered. We were cleared to keep the sensors in the pond for the duration of this project, and planned to remove it when the students were done collecting data.

Technological Development

Prototype

As stated above, we decided on three sensors: a TDS sensor, a turbidity sensor, and a temperature sensor. For our prototype sensing package, all three sensors were secured in a waterproof casing, with the waterproof components protruding from the sides (Figure 5).

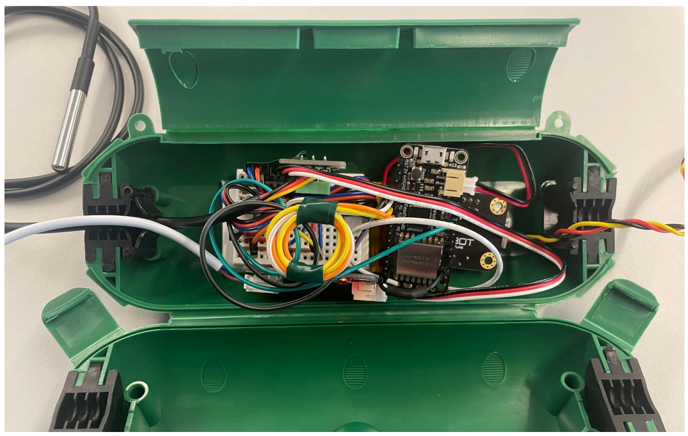

Figure 5: Final Package Insides

Sensor Physics and Working Principles

Turbidity

Manufacturer: DFRobot
Model Number: SEN0189

Turbidity describes how clear a sample of water is. Low turbidity means the water is more clear and has few particles. High turbidity signifies cloudier water and more particles. When particles are present, light passing through the water bounces off of them in different directions. A turbidity sensor works by shining light into the water and photo detector sensors that are "able to detect very small changes (attenuation) of transmitted light intensity" [3]. These photo detector sensors measure how much light is scattered and translates this measurement to a turbidity value.

Temperature Sensor

Manufacturer: Bojack
Model Number: BJ-TSMK

A temperature sensor contains a resistor that changes resistance with temperature. More specifically, this Resistance Temperature Detector (RTD) "…works following a basic principle of when the temperature of a metal increases, the resistance to the flow of electricity increases as well" [4]. This resistance is quantified and converted to a temperature value. For a waterproof sensor like ours, the resistor is placed inside a waterproof component. As the water heats or cools the surrounding metal, the resistor inside detects this change. We used a BOJACK DS18B20 sensor which comes with a PCB to attach the probe to and an Arduino library, DallasTemperature with OneWire, with functions that convert the output readings to either Fahrenheit or Celsius. We chose to display them in Fahrenheit for students.

<u>Water Conductivity (or Total Dissolved Solids) Sensor</u>
Manufacturer: Garosa
Model Number: B08SQGL728

Water Conductivity sensors, also known as Total Dissolved Solids sensors, "...work by passing an electrical current through a solution and measuring the amount of current that flows through the solution" [5]. This current is used to calculate conductivity, which can then be converted into a Total Dissolved Solids (TDS) value using a conversion factor. Higher conductivity indicates more dissolved ions. The conversion factor accounts for the typical relationship between conductivity and dissolved solids, considering the nature of the ions commonly found in water, and the value ranges from 0 to 1000 ppm [6]. The higher the output value, the more impurities or particulates in the water. Pure water usually reads a value of 10, while tap water is roughly 100.

Justification for Sensors

The decision to use these sensors is in line with our vision and design goals. Our goal was for the students to understand the Internet of Things and how it is useful, and we believed this education project would be effective if they built off of knowledge they already had. According to our community partner Kirsten, the students were interested in preserving the environment and they had experience collecting and analyzing data. These three sensors measure turbidity, temperature, and total dissolved solids, all properties commonly used to report on the quality of water. More importantly, the specific models of sensors that we chose came with clear design manuals that were useful for teaching, and they each had video or pictorial tutorials online. In order to focus on understanding the IoT component of the project, we needed to choose materials that allowed us to quickly teach the mechatronics component.

Prototype and Sensor Integration

After our first lesson with the students, we gave them the task of thinking how the circuits could be waterproofed. This allowed them to be creative and engage in the engineering process and see an aspect of their own design reflected in the final product. We purchased a smaller sized version of the case the students recommended, and the circuitry fit inside such that the temperature and conductivity probes could protrude from one end and the turbidity sensor from the other (Figure 6). The probes were both fully waterproof, but we required additional waterproofing methods for the turbidity sensor cables.

The casing was a cover designed for outdoor use over extension cord connections. It was advertised as “waterproof,” but we had reasons to believe this actually meant “water resistant,” as the product was not intended to be fully submerged in water. The case was made of polypropylene plastic with four corner clips and a large snap-on locking connection in the middle. The sides which the wires exited from were sealed with rubber gaskets, which were the main concern in our use of this case. While designed to hold wires, the gaskets were not totally water tight, even less so when two wires stuck out together. Therefore a few waterproofing and weatherproofing measures were taken. We first applied heat shrink tubing around the turbidity sensor’s wire and exposed section of the JST connector housing, as well as a sealant and varnish to the plastic casing around the sensor. Specifically, the products used were hot glue and clear nail polish. The materials for this waterproofing method are accessible, thus making repeatability very feasible. Nail polish is made of acrylic resin particles suspended in butyl acetate, which means that once it dries it forms a solid barrier composed of these acrylic particles. Hot glue is a type of thermoplastic adhesive, which is very malleable above the temperature of 100 ºC, which makes it perfect for filling gaps in this state, and once it dries it hardens. The varnish was applied on top of the sealant to add a layer of protection against the elements.

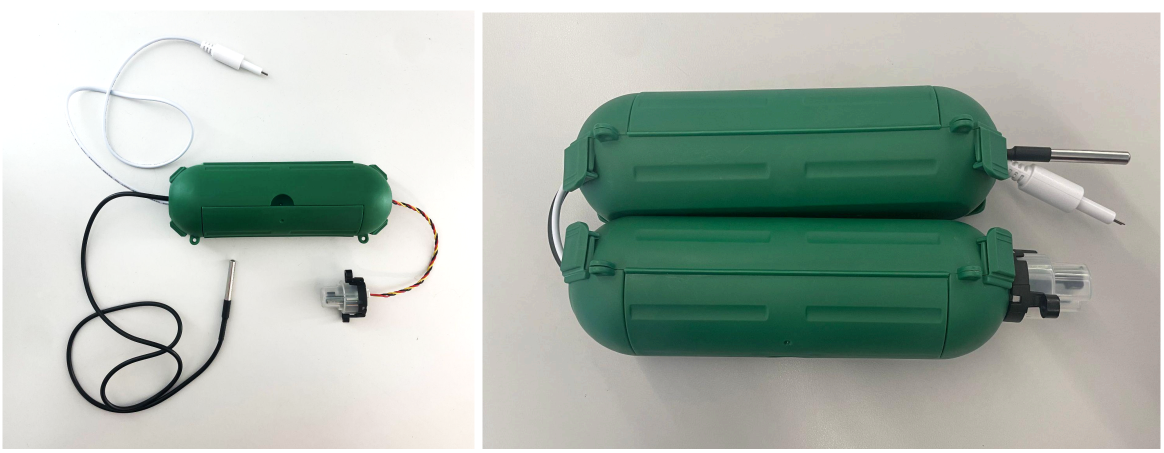

Figure 6: Sensors Packaged Inside of Module with one case (left) and two cases (right)

Logging and Sending Data to the Internet

The module contained the sensor circuitry along with the featherboard (Figure 7), which communicated with a Multitech Conduit LoRaWAN gateway. The system sketch is shown as a circuit diagram (Appendix 5, Figure 1A). We examined the site and determined that a gateway could be placed in a nearby classroom with a line of sight to the pond. However, after disabling that gateway, our sensor package connected to a gateway located at the Boys and Girls club across the street from the high school that gave us consistent packages. We considered extending the featherboard antenna outside of the casing, but it was not necessary and data was still successfully sent.

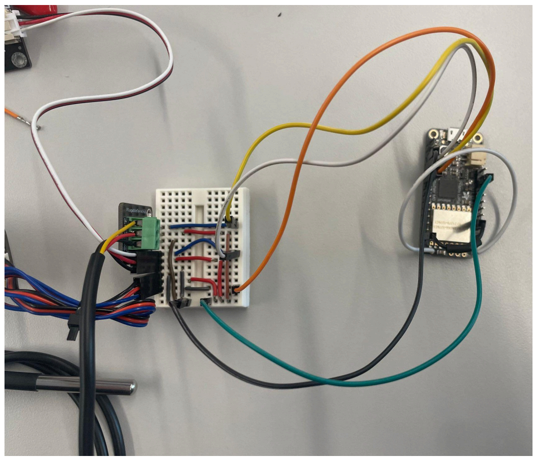

Figure 7: Breadboard connecting Featherboard and Sensors

The sensors collected data and sent the values to TTN using a package containing three float values, one for each sensor measurement (Appendix 2). The package was received and decoded into the individual values (Appendix 3). Data collection occurred every 30 seconds which was ideal for student viewing but not necessarily long term data collection, a decision we made due to the device's limited power supply as discussed later. Data processing such as decoding input values to have interpretable meaning was all done within the featherboard code, and the final values were sent to TTN. This was especially important to students who could have found the decoding intimidating but could understand these final values and how they reflected the data being read from the real world.

Data Storage, Management and Presentation to Community Partner

Data for the project was collected for approximately 72 hours before the battery in the device ran out of charge. This collection was done through the TTN website's live data and a Python script (Appendix 4) capturing the readings. A gateway was initially set up for temporary readings in a GHS classroom with a clear line of sight to the pond, but after testing our readings we found that the device reached a gateway from the Boys and Girls club across the street. Data collected from the Python script was compiled into graphs (Figure 8) and presented to Kirsten and the students, along with a worksheet explaining how to interpret the values (Appendix 7). Kirsten was given permission to use the data for any lessons she would like, and allow the students to perform analysis on the data how they see fit.

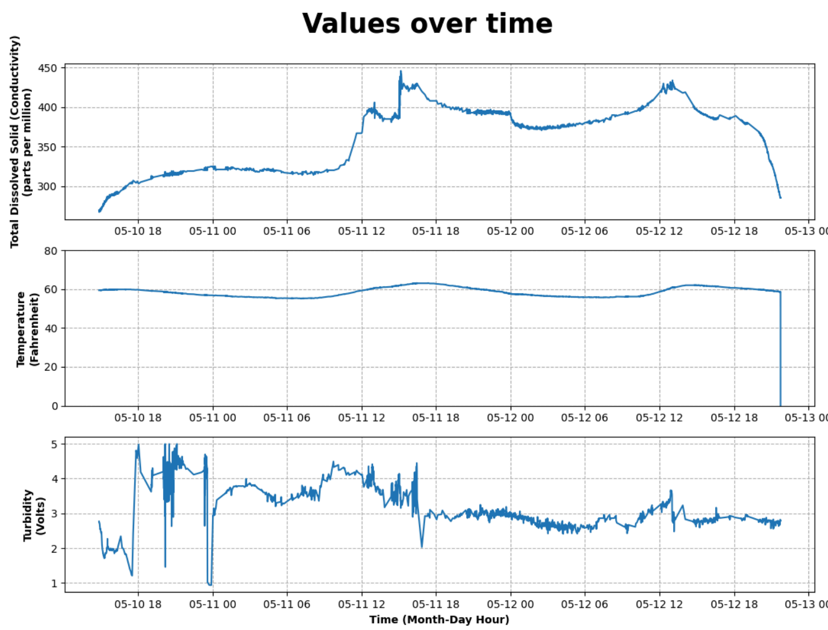

Figure 8: Data collected from 5/10-5/12

Power Management

We used a 3.7V, 1200mAh lithium ion polymer battery to power the device. The specifications of the battery had to comply with voltage requirements of the featherboard, and that of the sensors. Most importantly, the specifications had to comply with the turbidity sensor since it relied on voltage change as a way to convey measurements of turbidity. The electric charge of the battery had to last an adequate amount of time. We were limited by the size of the case, so we settled for a battery with dimensions that could fit the case, but had a lower mAh specification compared to other batteries of the same kind. 1200mAh allowed the device to run the sensors continuously for approximately 72 hours, which was adequate enough for our project. If the device were programmed with appropriate wake sleep cycles, the potential of this battery could have spanned to powering the device for months.

Field Deployment

On Friday May 10th, 2024, we met with the students at Geneva high school during their class period to deploy the device in the pond. We attached the sensor packages to a stick using duct tape, then inserted it deep into the pond floor (Figure 9). The casing body was left suspended above the water surface, while only sensors' ends were fully submerged into the water.

Figure 9: Area of Deployment in the Pond

Communication Protocol Justification

By sending the data to TTN directly, we were able to show the students the live data coming in while we were at the school deploying the device. The data did not need to be stored long term, so we decided there was no need for a FRAM or SD card. If Kirsten was interested in a longer term project of data collection with the students, we could have implemented these additional storage methods into the module with some modification. Due to time constraints (see our timeline in Appendix 6), we were unable to create a TTN account for the students to view live data as it was coming in. Instead, we created graphs with the data in Python, since the students were familiar with that format of data presentation.

Plan for Next Steps

Our team made major developments in the project compared to the previous iteration. We were able to deploy a new device and implement a new mode of educating students about IoT. However, there is still a lot of room for improvement, and proposals we have for where the project could go next. We believe this project has the most potential as a form of long term data collection for the students.

The biggest area to next iterate upon is device power. We used a single 3.7V 1200mAh Lithium Ion Polymer battery to power the device, which read sensors and sent a package every 30 seconds so students could see data coming through. Ideally, packages should only be sent every 30-60 minutes to visualize data over a period of days or weeks. This would be most efficient for power consumption as well as data collection, as the readings do not change significantly minute to minute. Since the device would not be sending data often enough to justify a continuous supply of power, a sleep-wake cycle could be implemented to conserve battery power over extended periods. The Lithium Ion Polymer battery we implemented in our design was ideal for featherboards, but other options may be viable including solar power for the low energy consumption of our outdoor module. The device also does not currently have any form of memory storage device such as a FRAM or SD card, which is another area that could be iterated upon. It would be useful to back up our readings on some sort of hardware if a problem arises with TTN or the gateway.

There is also major room for improvement in student engagement and curriculum integration. Kirsten teaches an AP Environmental Sciences course some years and Chemistry other times. This year she had a Chemistry class, which we collaborated with, but the themes of water quality are more relevant to her AP Environmental class. We believe that the correlation between the student's coursework in environmental science and the data collected by the device will be more engaging to students, as they will be more familiar with interpretations of that kind of data. Additionally, the data we provided students with was raw data read from the sensors (excluding the temperature data which was in degrees Fahrenheit.) To give students a better understanding of what values of Turbidity and Total Dissolved Solid actually mean, we could create an artificial scale (say, 1 to 10) which the students can more easily interpret, then translate the data to that scale.

Some minor improvements could include further or more robust waterproofing of sensors and the module, providing a gateway to GHS rather than relying on the Boys and Girls club gateway, and adding a flotation system to the device so that sensors will not lose contact with the water when water levels change. These were all ideas we discussed for our device and barriers which might obstruct the collection of data. To make this effort sustainable, it is important to communicate with GHS about permanent placement of a water quality sensor or a gateway on their campus, as they will have to work out property logistics.

Finally, the students will be most engaged with IoT and STEM education if IoT lessons are fully integrated into their course. This is a large step from where our project is at now, but our ultimate goal would be to have STEM education be a regular part of high school courses, beyond only Kirsten's class. IoT and other forms of engineering are not necessarily subjects to be taught in a class exclusively related to them, but platforms which much of the world is built upon. Data collection through IoT can be applied to any field of study and students can be engaged with this idea if IoT is applied within their classrooms. Teachers should be encouraged to update their curriculums to integrate this technology into regular lessons, which will give students more interactive experience with live data and boost their understanding of course material if they can see how numerical data reflects real, observable changes.

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APPENDIX:

Appendix 1: Bill of Materials

Table 1A: Bill of Materials

Part name (attach link)	Purpose	Dimensions (lxwxh)	Supplier	Qt. Needed	Qt. in Package	# Packages	Price Per Unit	Price per Package	Total Price
Featherboard	Hardware component that allows sensor input to be converted to computer data	0.9"x2"	Provided by IoT course	4	1	1	-	-	-
Wires (MM/FF/MF)	Connect our sensors and other components	0.04" x 8.27" x 0.04"		~50	120	1	$0.06	$6.98	$6.98
Mini breadboards	Used to connect complete assembly.	82mmx54mmx9mm	Amazon	4	6	1	$1.50	$8.99	$8.99
Turbidity sensor	Hardware component that collects data of turbidity of water		Digikey	3	1	3	$9.90	$9.90	$29.70
Temperature probe	Measures the temperature of the water by its probe		Amazon	2	1	2	$8.99	$8.99	$17.98
Water Conductivity Sensor	Measures the total dissolved solids in a water sample		Amazon	2	1	2	$14.71	$14.71	$29.42

Lithium Ion Polymer Battery	Power source compatible with Turbidity sensor and Featherboard		Adafruit	2	1	2	$9.95	$9.95	$19.90
LiPoly Charger	Charger for Lithium Ion Battery		Adafruit	1	1	1	$12.50	$12.50	$12.50
Outdoor Extension Cord Cover	Casing to be adapted into storage for our sensors		Amazon	1	3	1	$4.93	$14.79	$14.79

Appendix 2: Uploaded Code, Encapsulated in Functions to Simplify for Students (C++)

```
//NEEDED TO INSTALL DALLAS TEMPERATURE WITH ONEWIRE FOR TEMPSENSOR

#include <OneWire.h>

#include <DallasTemperature.h>


#include <lmic.h>

#include <hal/hal.h>

#include "keys.h"

#include <Arduino_LoRaWAN_ttn.h>


struct __attribute__((__packed__)) DataPackage{

  float temperature;

  float turbidity;

  float conductivity;

};


DataPackage waterDataPackage;


#define ONE_WIRE_BUS A1


// Setup a oneWire instance to communicate with any OneWire devices
```

```
OneWire oneWire(ONE_WIRE_BUS);

// Pass our oneWire reference to Dallas Temperature sensor
DallasTemperature tempsensors(&oneWire);

//Define arduino variables
uint64_t lastTime = 0;
uint32_t bufferLength = 8;
static uint8_t messageBuffer[8] = {0, 1, 2, 3, 4, 5, 6, 7};

#ifdef __cplusplus
extern "C"{
#endif

void myStatusCallback(void * data, bool success){
  if(success)
    Serial.println("Succeeded!");
  else
    Serial.println("Failed!");
}

#ifdef __cplusplus
}
#endif

class cMyLoRaWAN : public Arduino_LoRaWAN_ttn {
public:
    cMyLoRaWAN() {};

protected:
    // you'll need to provide implementations for each of the following.
```

```
    virtual bool
GetOtaaProvisioningInfo(Arduino_LoRaWAN::OtaaProvisioningInfo*) override;

    virtual void NetSaveSessionInfo(const SessionInfo &Info, const uint8_t
*pExtraInfo, size_t nExtraInfo) override;

    virtual void NetSaveSessionState(const SessionState &State) override;

    virtual bool NetGetSessionState(SessionState &State) override;

    virtual bool
GetAbpProvisioningInfo(Arduino_LoRaWAN::AbpProvisioningInfo*) override;


};


// set up the data structures.

cMyLoRaWAN myLoRaWAN {};


// The pinmap. This form is convenient if the LMIC library

// doesn't support your board and you don't want to add the

// configuration to the library (perhaps you're just testing).

// This pinmap matches the FeatherM0 LoRa. See the arduino-lmic

// docs for more info on how to set this up.

const cMyLoRaWAN::lmic_pinmap myPinMap = {

     .nss = 8,

     .rxtx = cMyLoRaWAN::lmic_pinmap::LMIC_UNUSED_PIN,

     .rst = 4,

     .dio = { 3, 6, cMyLoRaWAN::lmic_pinmap::LMIC_UNUSED_PIN },

     .rxtx_rx_active = 0,

     .rssi_cal = 0,

     .spi_freq = 8000000,

};



void sendPackage(DataPackage newPack){

  messageBuffer[0]++; //increment 1st byte by 1
```

```
  myLoRaWAN.SendBuffer((uint8_t *) &newPack, sizeof(newPack),
myStatusCallback, NULL, false, 1);

  lastTime = millis();

}


void beginSensors(){

    Serial.begin(115200);

    // {

    //   uint64_t lt = millis();

    // while(!Serial && millis() - lt < 5000);

    // }

  myLoRaWAN.begin(myPinMap);

  lastTime = millis();

  tempsensors.begin();

  //LMIC.datarate = 10;

}

float getTemperature(){

  tempsensors.requestTemperatures();

  return tempsensors.getTempFByIndex(0); //Farenheit

  //return sensors.getTempFByIndex(0); //Celcius

}


float getTurbidity(){

  int sensorValue = analogRead(A2);// read the input on analog pin 0:

  float voltage = sensorValue * (5.0 / 1024.0); // Convert the analog
reading (which goes from 0 - 1023) to a voltage (0 - 5V):

  return voltage;

}

float getConductivity(){

  int sensorValue = analogRead(A0);// read the input on analog pin 0:

  return(sensorValue); // print out the value you read:
```

```
}

void setup() {
  //First you must tell the sensors to turn on
  beginSensors();
  //Then collect an initial reading of each sensor
  waterDataPackage.temperature = getTemperature();
  waterDataPackage.turbidity = getTurbidity();
  waterDataPackage.conductivity = getConductivity();
  //Fancy way of saying send the first set of data
  myLoRaWAN.SendBuffer((uint8_t *) &waterDataPackage,
sizeof(waterDataPackage), myStatusCallback, NULL, false, 1);
}
void loop() {
  //Loop means the code continues to run over and over
  myLoRaWAN.loop();
  uint32_t secondsSinceLastSent = (millis() - lastTime)/1000;

  //Collect and send the data every 30 seconds
  if (secondsSinceLastSent > 30){
    waterDataPackage.temperature = getTemperature();
    waterDataPackage.turbidity = getTurbidity();
    waterDataPackage.conductivity = getConductivity();
    sendPackage(waterDataPackage);
    }
}

// this method is called when the LMIC needs OTAA info.
// return false to indicate "no provisioning", otherwise
// fill in the data and return true.
bool
```

```
cMyLoRaWAN::GetOtaaProvisioningInfo(
    OtaaProvisioningInfo *pInfo
    ) {
      if (pInfo){
        memcpy_P(pInfo->AppEUI, APPEUI, 8);
        memcpy_P(pInfo->DevEUI, DEVEUI, 8);
        memcpy_P(pInfo->AppKey, APPKEY, 16);
      }
    return true;
}

void
cMyLoRaWAN::NetSaveSessionInfo(
    const SessionInfo &Info,
    const uint8_t *pExtraInfo,
    size_t nExtraInfo
    ) {
    // save Info somewhere.
}
void
cMyLoRaWAN::NetSaveSessionState(const SessionState &State) {
    // save State somwwhere. Note that it's often the same;
    // often only the frame counters change.
}
bool
cMyLoRaWAN::NetGetSessionState(SessionState &State) {
    // either fetch SessionState from somewhere and return true or...
    return false;
}
bool
cMyLoRaWAN::GetAbpProvisioningInfo(Arduino_LoRaWAN::AbpProvisioningInfo*
```

```
Info){

  //either get ABP provisioning info from somewhere and return true or...

  return false;

}
```

Appendix 3: Uplink Code (Javascript)

```
      function decodeUplink(input) {
        //initialize an object to store output data
        var water_data = {}
        water_data.temperature =
floatFromBytes(input.bytes.slice(0,4));
        water_data.turbidity =
floatFromBytes(input.bytes.slice(4,8));
        water_data.conductivity =
floatFromBytes(input.bytes.slice(8,12));

        //return the output data along with any errors or warnings
        return {
           data: water_data,
           warnings: [],
           errors: []
        };
      }

      function floatFromBytes(bytes) {
           var bits = bytes[3]<<24 | bytes[2]<<16 | bytes[1]<<8 |
bytes[0];
           var sign = (bits>>>31 === 0) ? 1.0 : -1.0;
           var e = bits>>>23 & 0xff;
           var m = (e === 0) ? (bits & 0x7fffff)<<1 : (bits &
0x7fffff) | 0x800000;
           var f = sign * m * Math.pow(2, e - 127-23);
           return f;
        }
```

Appendix 4: Package Download Code (Python)

```
#!/usr/bin/env python3

# from
https://stackoverflow.com/questions/54292179/saving-mqtt-data-from-subscribe-topic-on-a-text-file
```

```python
import paho.mqtt.client as mqttClient
import time

def on_connect(client, userdata, flags, rc):


   if rc == 0:

       print("Connected to broker")

       global Connected                #Use global variable
       Connected = True                #Signal connection

   else:

       print("Connection failed")

def on_message(client, userdata, message):
   print("")
   print("Message received: "  + str(message.payload))

   with open('pondData.txt','a+') as f:
        f.write(str(message.payload)[2:-1]+"\n")

Connected = False   #global variable for the state of the connection

broker_address= "nam1.cloud.thethings.network"  #host
port = 1883                          #Broker port
user = "REDACTED FOR REPORT@ttn" #<--  Put your TTN V3 app here
#Connection username
password = "REDACTED FOR REPORT"

client = mqttClient.Client("Python")               #create new instance
client.username_pw_set(user, password=password)    #set username and password
client.on_connect= on_connect                      #attach function to callback
client.on_message= on_message                      #attach function to callback
client.connect(broker_address,port,60) #connect
client.subscribe(f"v3/{user}/devices/+/up") #subscribe
client.loop_forever() #then keep listening forever
```

Appendix 5: System Sketches

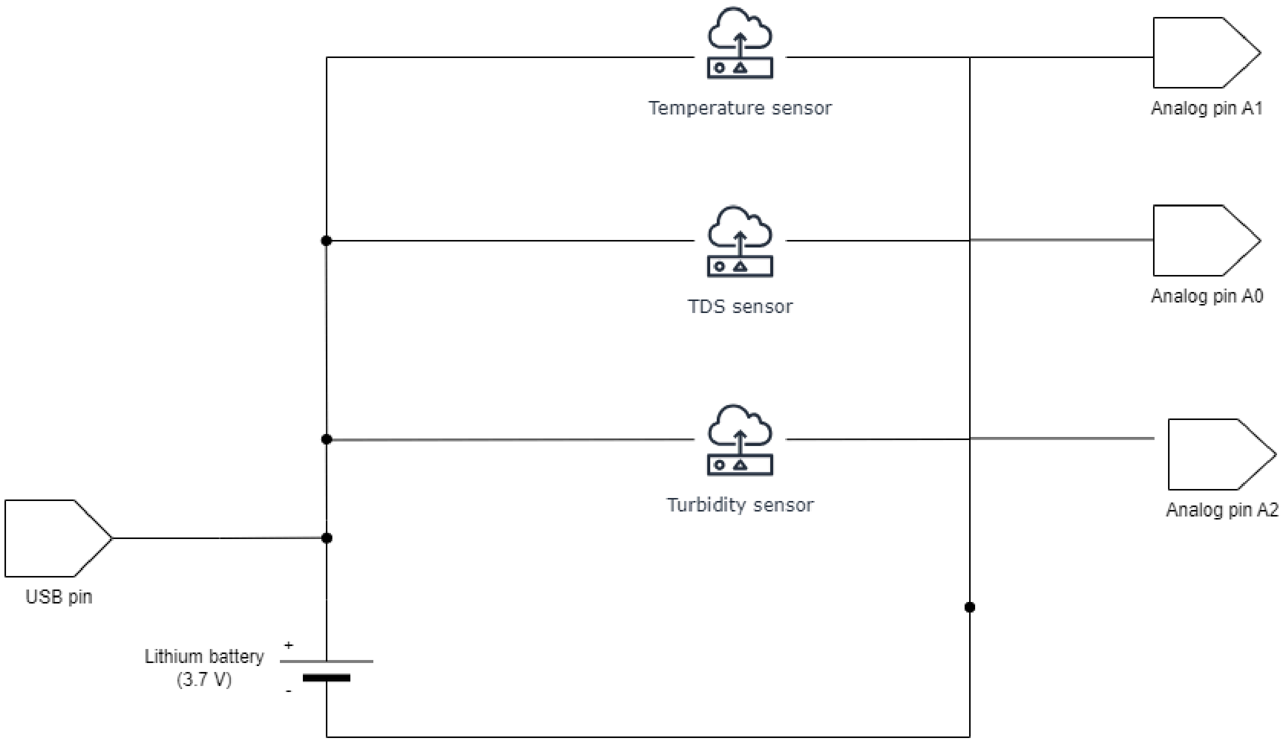


Figure 1A: Circuit Diagram of Sensor Package

Appendix 6: Project Timeline and Organization

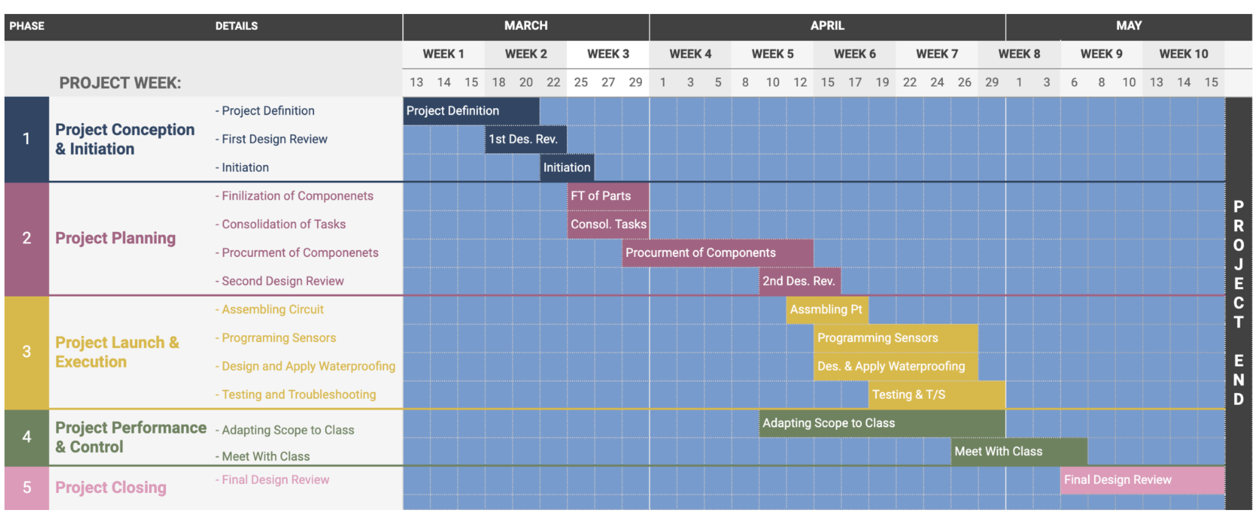


Figure 2A: Original Gantt Chart of Project

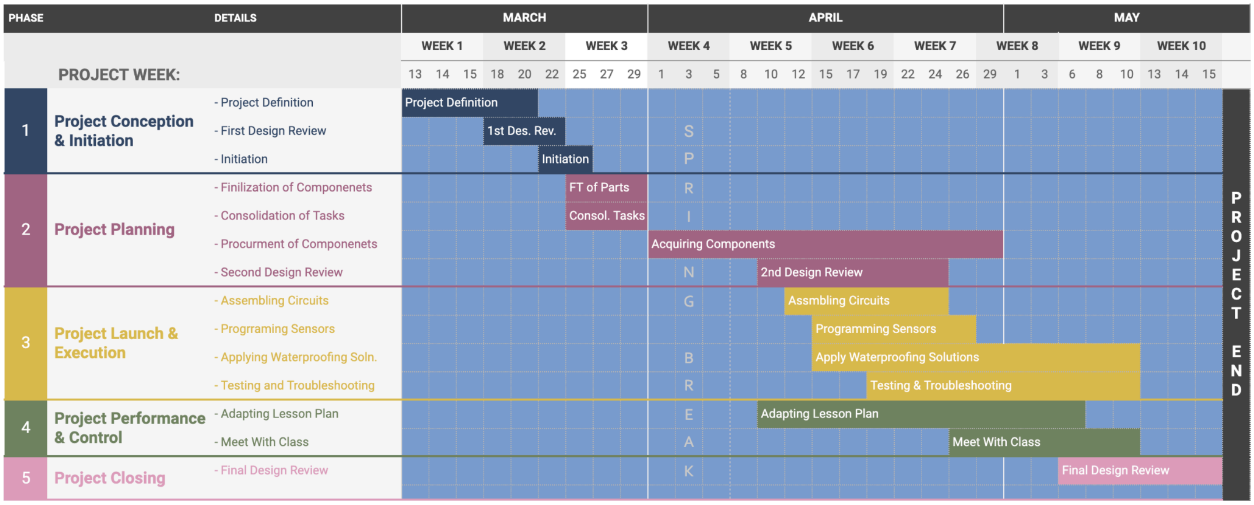
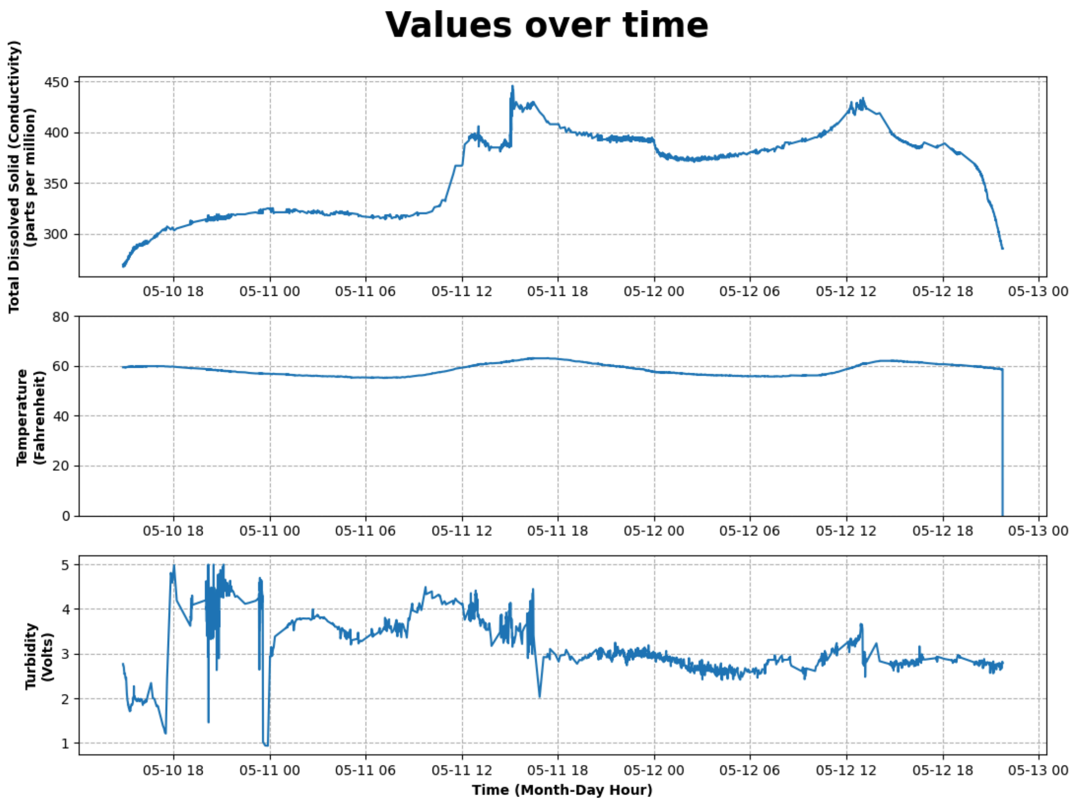


Figure 3A: Modified Timeline of Project

What does it mean? 🤔
Data Analysis Worksheet

Congratulations! You have now collected data from all three sensors that we put in the pond! In the graphs below, you will see the data that each sensor collected over time.



These graphs show the data that each sensor measured over time. The y-axes list each sensor and unit. The x-axis shows the time the data was collected. For example, 5-10 18 means the data was collected on May 5th at 6:00pm (the 18th hour of the day). The battery of the sensors died on May 12th at around 9:00 pm, which is why there is a sudden cutoff.

But what do all the numbers mean? Whenever you buy a sensor, it will come with a datasheet that tells you how to use it and how to interpret the data it gives you. Here is what the datasheets told us about each sensor:

Total Dissolved Solids sensor

Measurement range: 0 to 1000 ppm (parts per million)

Description: The higher the value, the more solids (sand, dirt, chemicals, etc.) are dissolved in the water.

Temperature sensor

Measurement range: -67 ℉ to +257 ℉

Description: This sensor tells you the temperature of the water in Fahrenheit.

Turbidity sensor

Measurement range: 0 to 5 volts

Description: The water has less turbidity when the voltage is higher, and higher turbidity when the voltage is lower. In other words, the closer to 5 volts, the clearer the water is.

Questions:

1) What was the temperature of the water on May 11th at noon?

2) True or false: The water was very clear on May 11th at midnight.

3) Around what day and time was the Total Dissolved Solids value highest?

4) Why do you think there was a rise in Total Dissolved Solids after May 11th?
Hint: It was rainy last weekend!

Appendix 8: Field Deployment

Figure 4A: Final Sensor Package Deployed in Pond

Figure 5A: Geneva High School student (left) and Cornell IoT team student (right) installing sensor package into pond at Geneva High School

Appendix 9: Aerial View of Geneva High School

Figure 6A: Aerial View of Geneva High School. The high school is labeled near the bottom left of the image. The pond can be seen in the top right of the image. The pond was about a five minute walk from the high school.

Appendix 10: Cornell IoT Team Presentations to Students